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(54) **OHMIC CONTACT ON P-TYPE GAN**

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(51) **Int. Cl.**
H01L 29/22 (2006.01)

(52) **U.S. Cl.** **257/614**; 257/744; 257/741; 257/750; 257/78; 257/191; 438/37

(58) **Field of Classification Search** .... None
See application file for complete search history.

(56) **References Cited**

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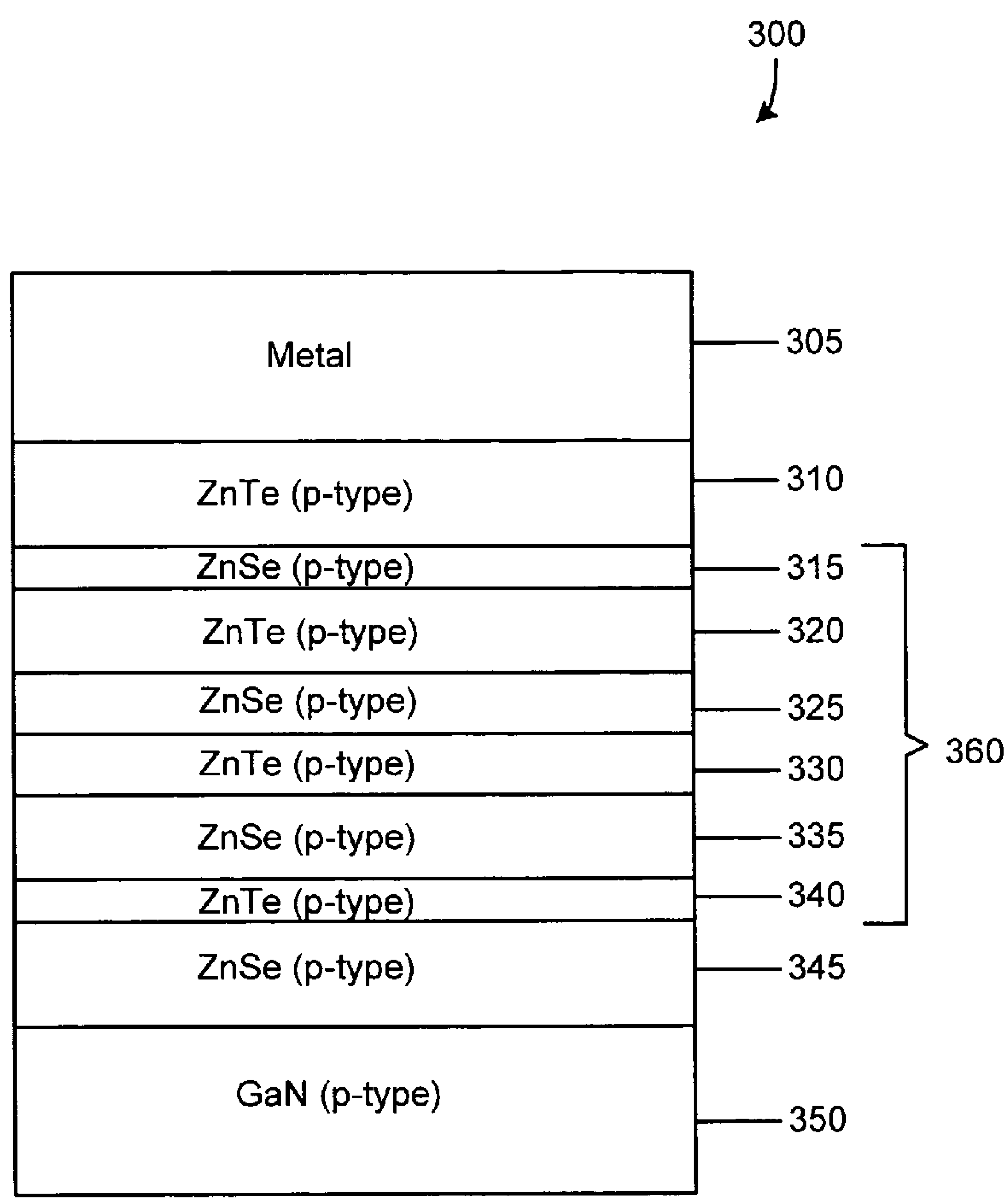
Assistant Examiner—Fei Fei Yeung Lopez

(57) **ABSTRACT**

An ohmic contact in accordance with the invention includes a layer of p-type GaN-based material. A first layer of a group II-VI compound semiconductor is located adjacent to the layer of p-type GaN-based material. The ohmic contact further includes a metal layer that provides metal contact. A second layer of a different II-VI compound semiconductor is located adjacent to the metal layer.

8 Claims, 7 Drawing Sheets



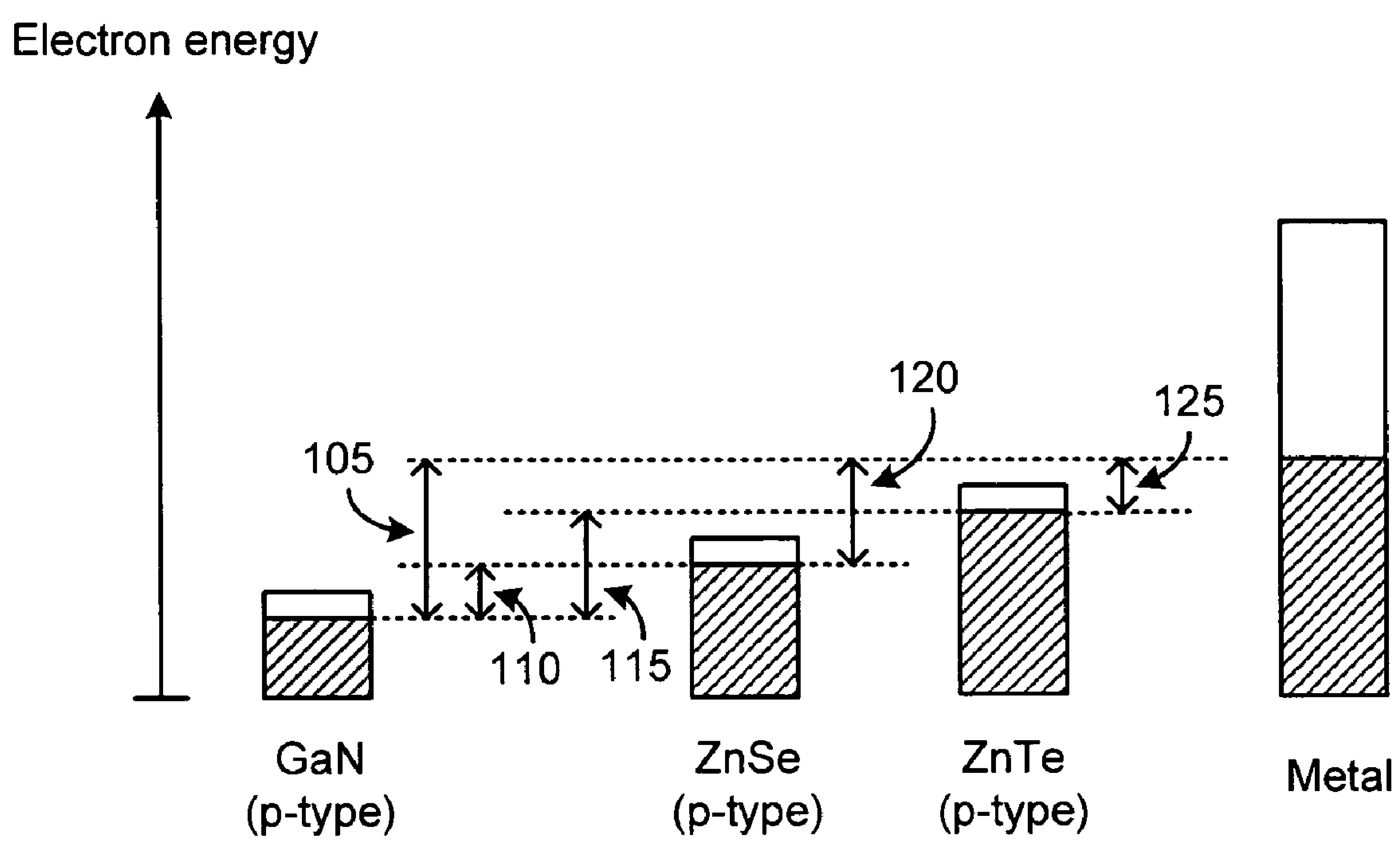

Electron energy
105
110
115
120
125
GaN
(p-type)
ZnSe
(p-type)
ZnTe
(p-type)
Metal

FIG. 1

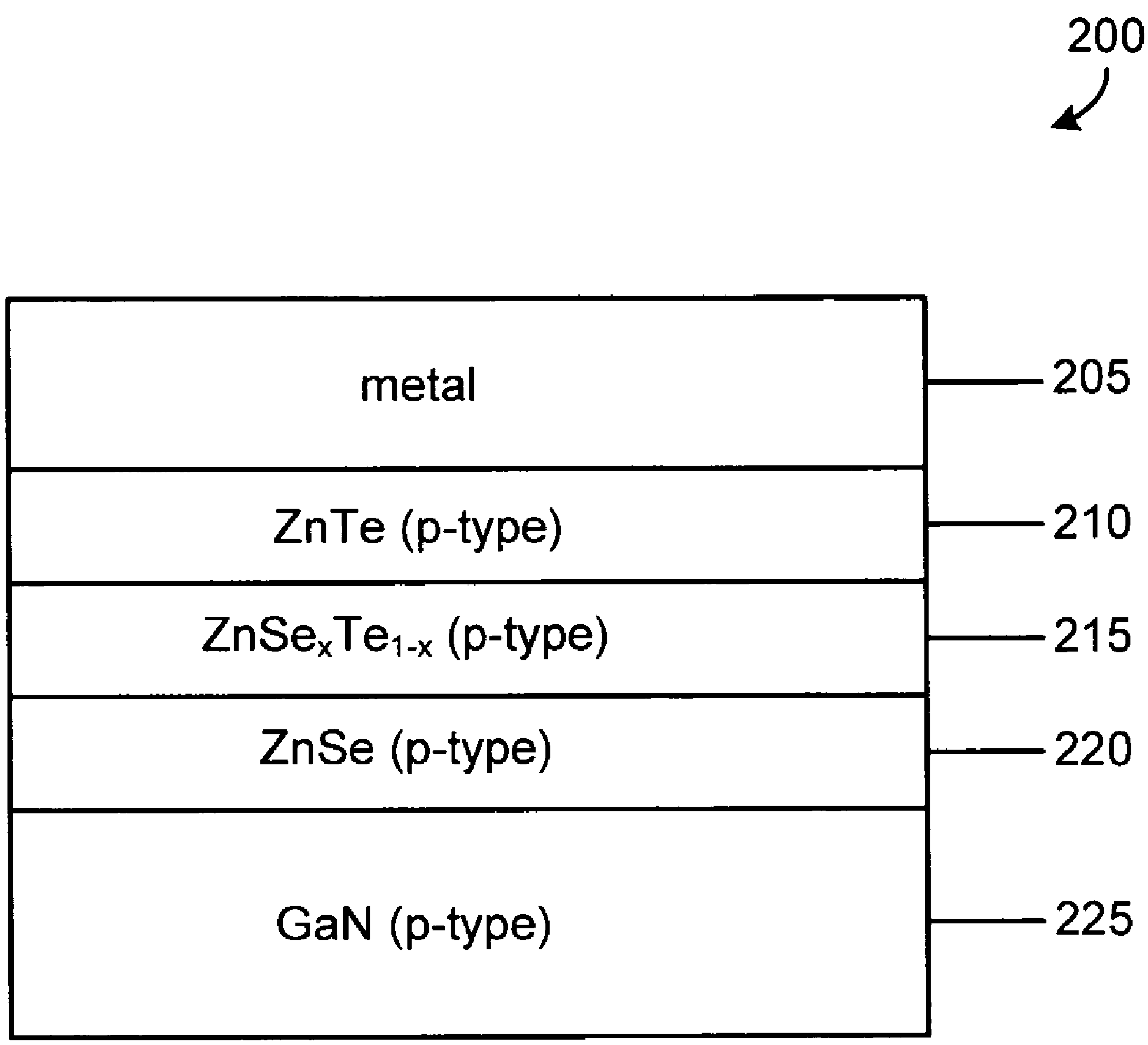

200
metal
205
ZnTe (p-type)
210
ZnSe$_x$Te$_{1-x}$ (p-type)
215
ZnSe (p-type)
220
GaN (p-type)
225

FIG. 2

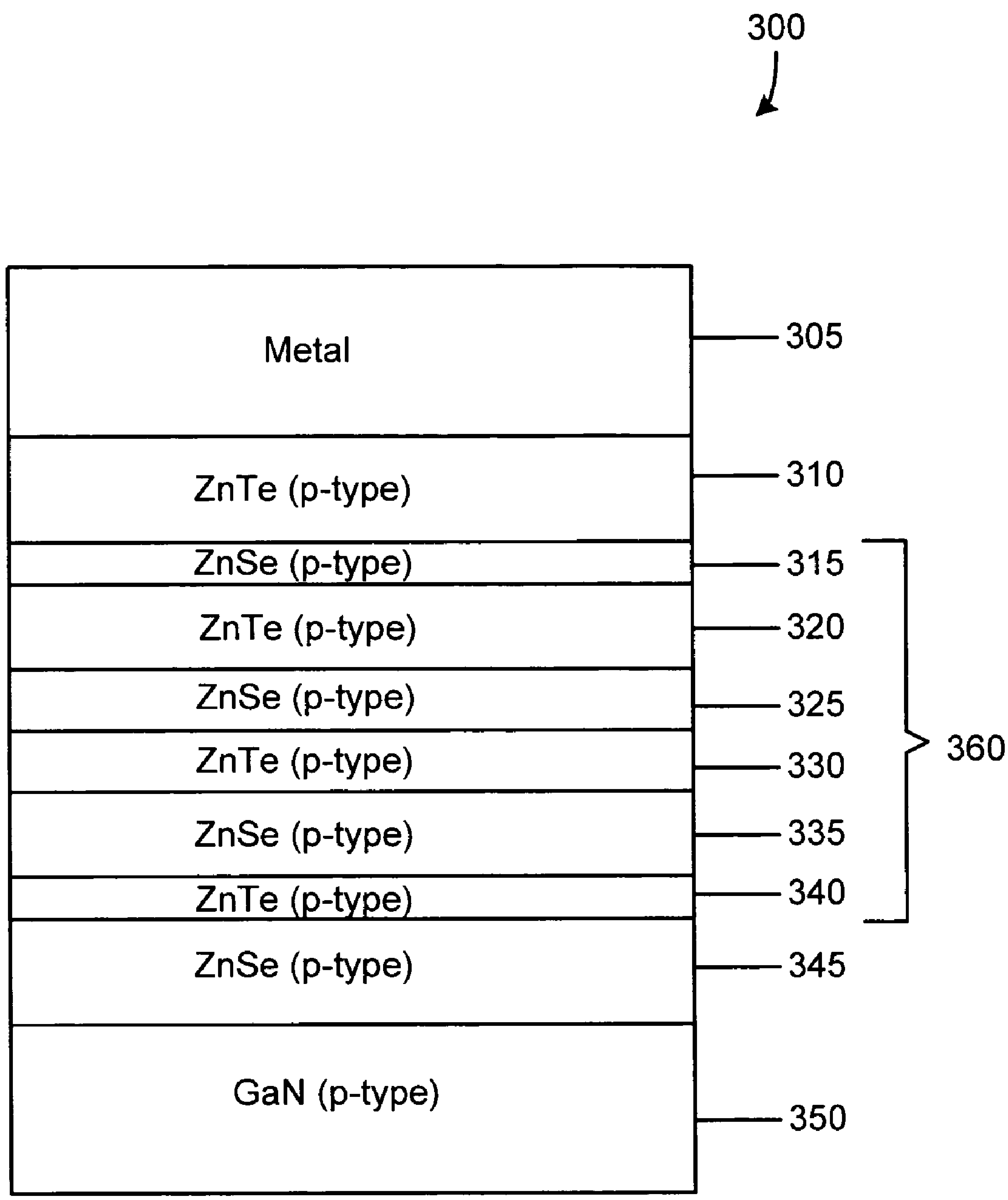

300
Metal
305
ZnTe (p-type)
310
ZnSe (p-type)
315
ZnTe (p-type)
320
ZnSe (p-type)
325
ZnTe (p-type)
330
ZnSe (p-type)
335
ZnTe (p-type)
340
ZnSe (p-type)
345
GaN (p-type)
350
360

FIG. 3

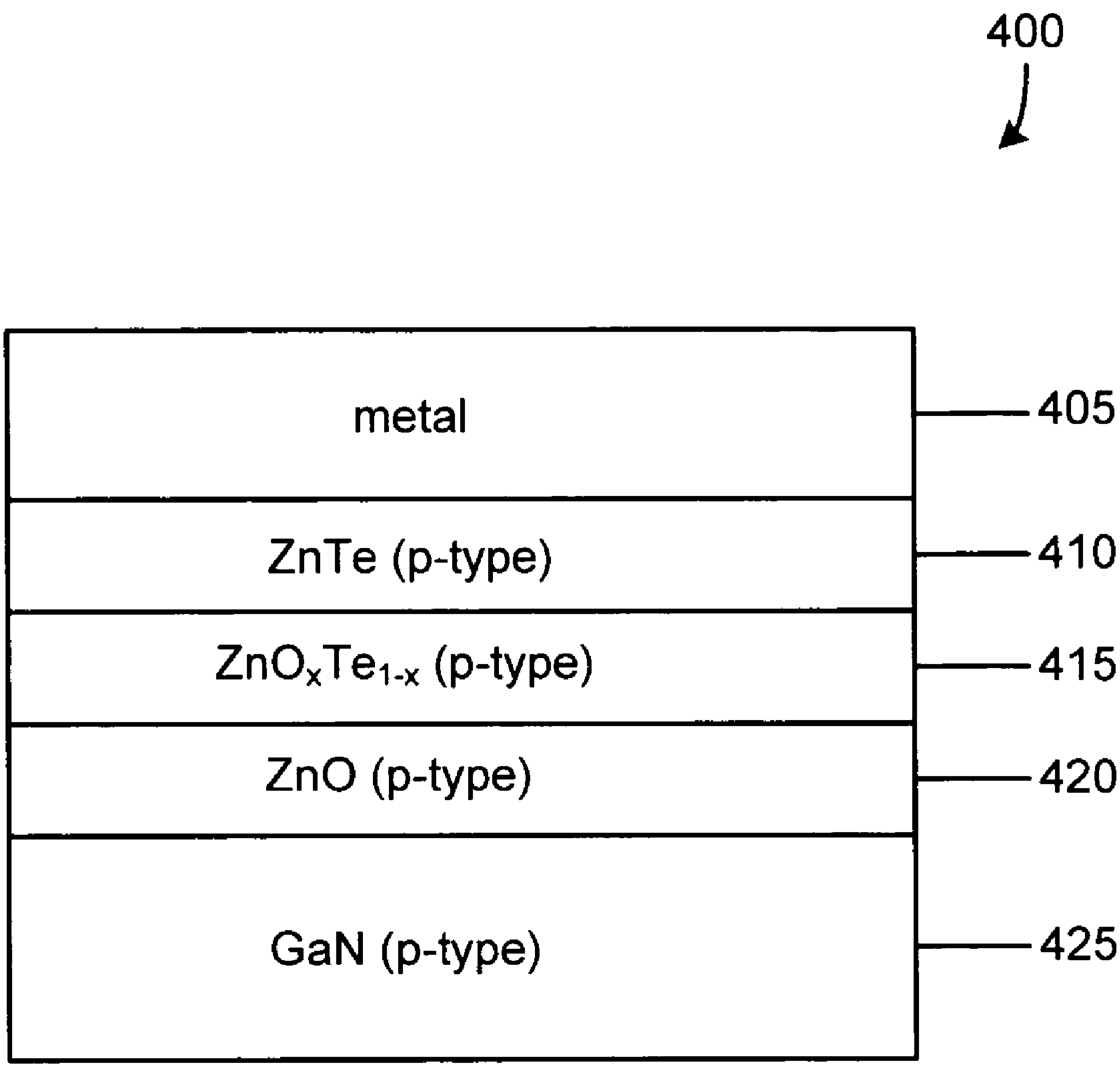

400
metal
405
ZnTe (p-type)
410
ZnO_xTe_{1-x} (p-type)
415
ZnO (p-type)
420
GaN (p-type)
425

FIG. 4

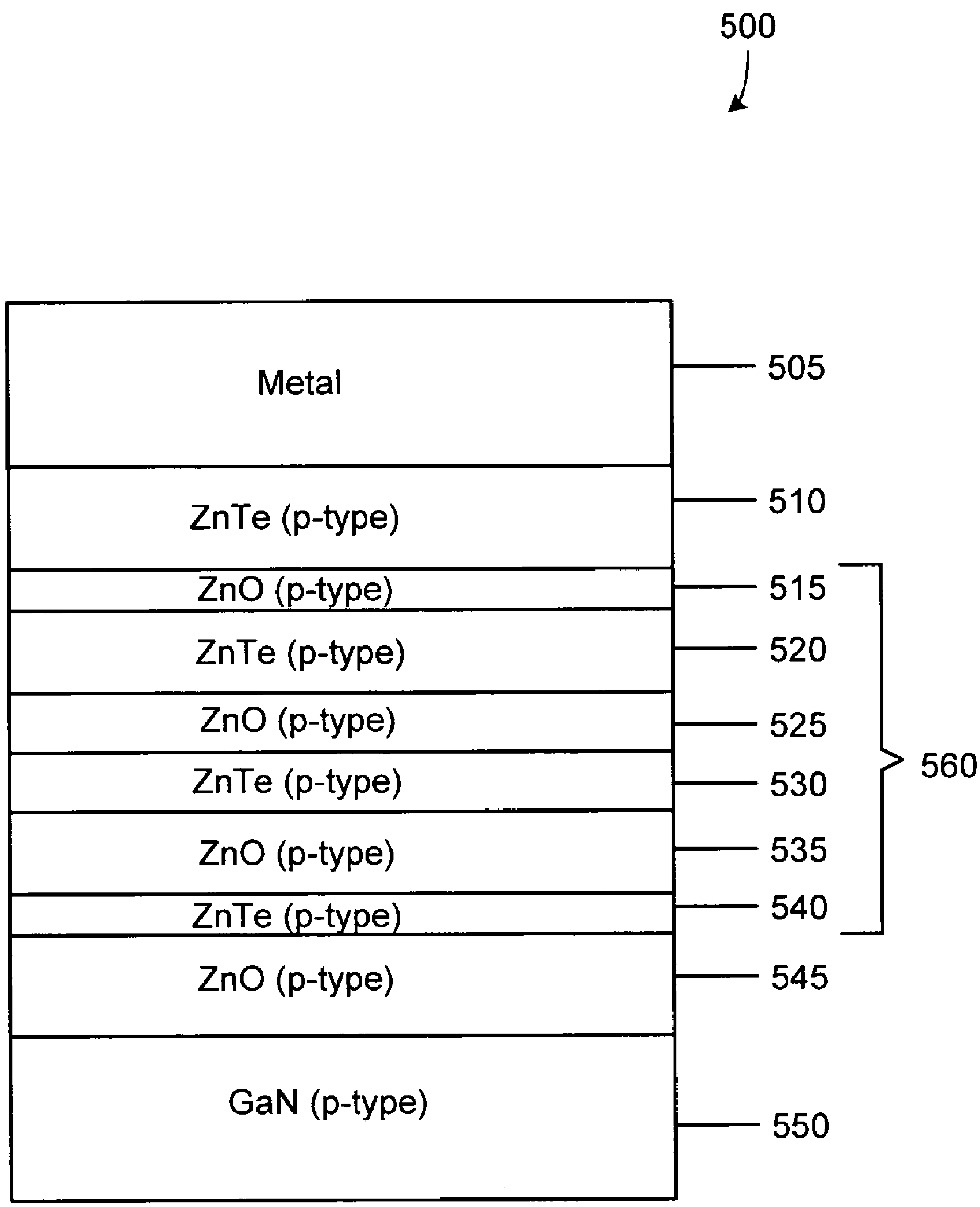

500
Metal
505
ZnTe (p-type)
510
ZnO (p-type)
515
ZnTe (p-type)
520
ZnO (p-type)
525
ZnTe (p-type)
530
ZnO (p-type)
535
ZnTe (p-type)
540
ZnO (p-type)
545
GaN (p-type)
550
560

FIG. 5

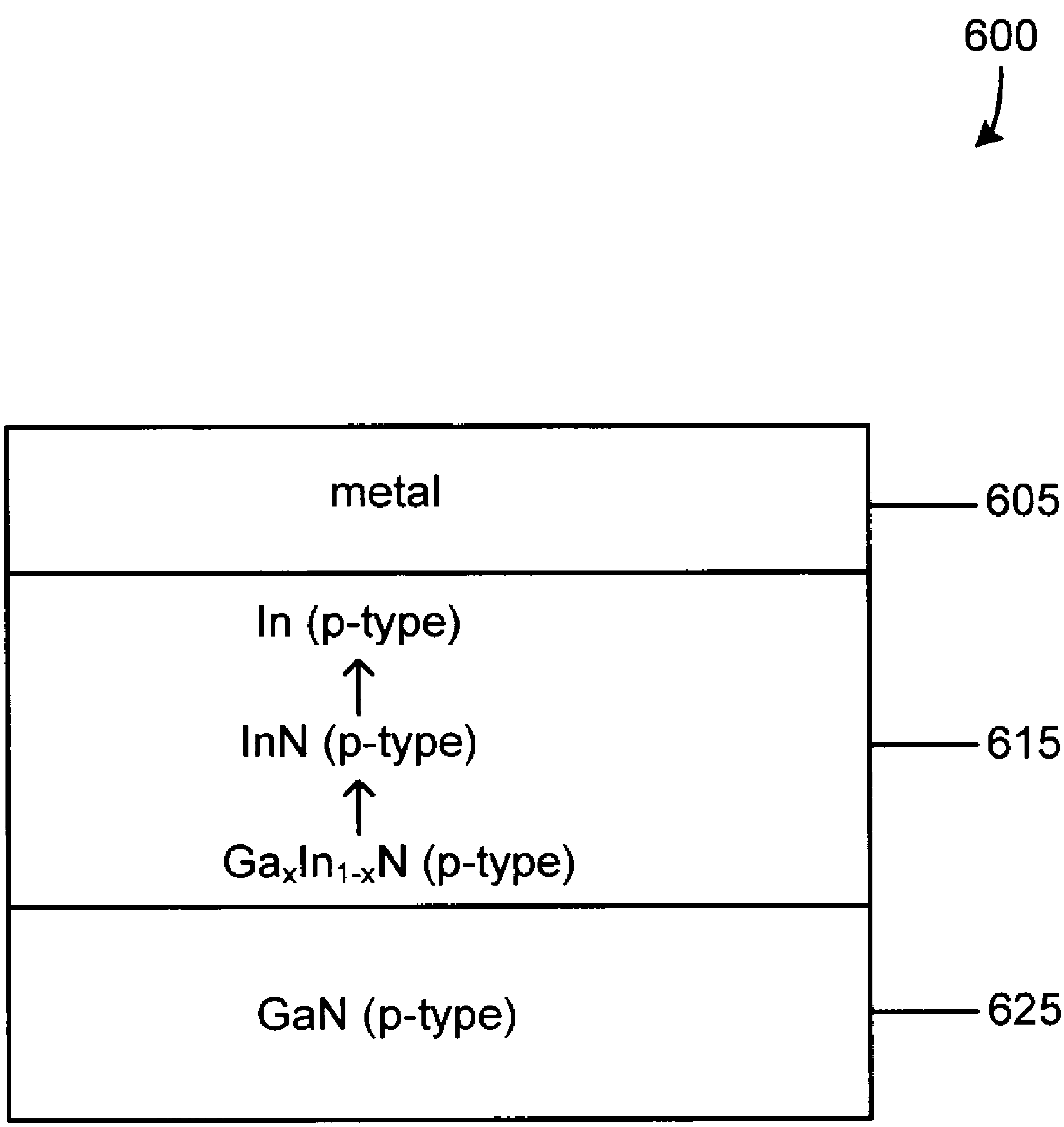

600
metal
605
In (p-type)
InN (p-type)
615
$Ga_xIn_{1-x}N$ (p-type)
GaN (p-type)
625

FIG. 6

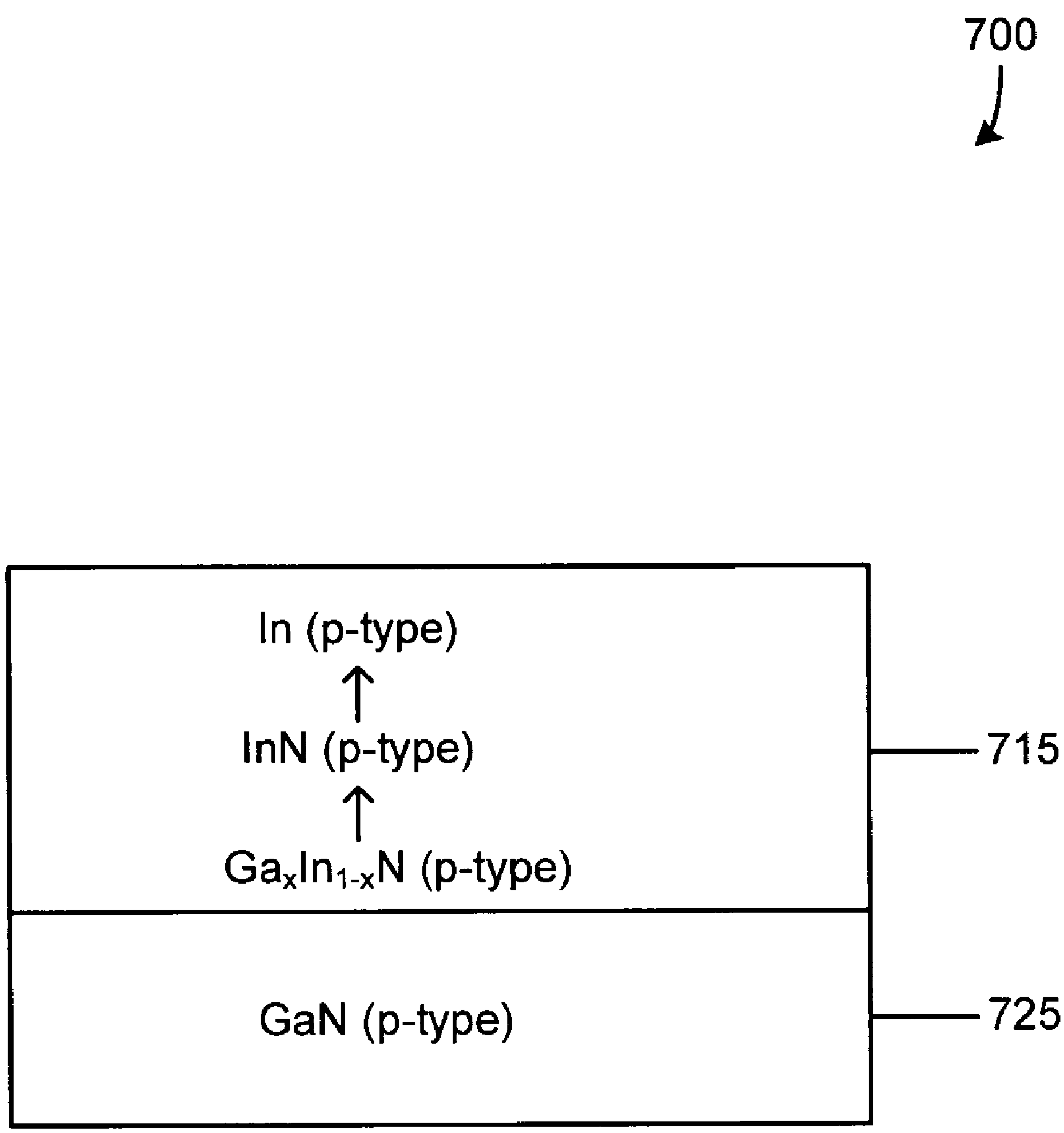


FIG. 7

OHMIC CONTACT ON P-TYPE GAN

DESCRIPTION OF THE RELATED ART

Providing an effective ohmic contact on a semiconductor surface, especially on a p-type semiconductor surface, has traditionally proven to be a challenge. This is in large part due to the presence of a significant valence band offset between the metal of the ohmic contact and the semiconductor material.

For example, an ohmic contact on a p-type semiconductor such as p-ZnSe has been traditionally implemented by evaporating gold on the semiconductor and soldering a bonding wire to the gold using indium metal. Unfortunately, the gold contact often forms a Schottky barrier with the p-type material thereby leading to a higher operating voltage, which in turn leads to generation of heat at the junction. Heat generation is undesirable because it can lead to device failure.

Several different solutions have been proposed to address the shortcomings related to providing an effective ohmic contact on semiconductor materials. For example, U.S. Pat. No. 5,548,137 "Group II-VI Compound Semiconductor Light Emitting Devices and an Ohmic Contact therefor," Fan et al, describes a low resistance ohmic contact on a Group II-VI compound semiconductor such as p-Zn(S, Se) or p-ZnSe. Per Fan et al, "the graded contact eliminates the valence band offset (≈1 eV) between a heterojunction of ZnTe and ZnSe which forms a barrier to hole injection."

While Fan et al addresses the issue of providing an ohmic contact upon a Group II-VI compound semiconductor, it is further desirable to provide effective ohmic contacts on several other semiconductor materials, including certain materials that have been incorporated in recent years into the manufacture of semiconductor devices such as light emitting diodes.

SUMMARY

An ohmic contact in accordance with the invention includes a layer of p-type GaN-based material. A first layer of a group II-VI compound semiconductor is located adjacent to the layer of p-type GaN-based material. The ohmic contact further includes a metal layer that provides metal contact. A second layer of a different II-VI compound semiconductor is located adjacent to the metal layer.

Clearly, some alternative embodiments may exhibit advantages and features in addition to, or in lieu of, those mentioned above. It is intended that all such alternative embodiments be included within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale. Instead, emphasis is placed upon clearly illustrating the principles of the invention. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** shows a valence band relationship between metal and certain p-type semiconductor compounds.

FIG. **2** shows a first exemplary embodiment of an ohmic contact in accordance with the invention.

FIG. **3** shows a second exemplary embodiment of an ohmic contact in accordance with the invention.

FIG. **4** shows a third exemplary embodiment of an ohmic contact in accordance with the invention.

FIG. **5** shows a fourth exemplary embodiment of an ohmic contact in accordance with the invention.

FIG. **6** shows a fifth exemplary embodiment of an ohmic contact in accordance with the invention.

FIG. **7** shows a sixth exemplary embodiment of an ohmic contact in accordance with the invention.

DETAILED DESCRIPTION

The various embodiments in accordance with the invention generally describe an ohmic contact formed on a p-type GaN-based material. Attention is now drawn to the figures that show various exemplary embodiments. It will be understood that when used below, positional terms such as "top" and "bottom," are used merely for ease of description and are not intended to limit the scope of coverage of the invention.

FIG. **1** shows a valence band relationship between metal and certain p-type semiconductor compounds. A metal such as gold has a large valence band offset **105** with respect to a p-type GaN-based semiconductor. The GaN-based semiconductor is represented by a general formula $In_xAl_yGa_{1-x-y}N$, where $(0 \leqq x \leqq 1)$ and $(0 \leqq y \leqq 1)$. When x=0, the GaN-based semiconductor is $Al_yGa_{1-y}N$ and when y=0, the GaN-based material is $In_xGa_{1-x}N$. The large valence band offset **105** leads to various shortcomings when a metal contact is formed directly on the GaN-based semiconductor.

Certain Group II-VI semiconductors have a smaller valence band offset with metal than the large valence band offset **105**. For example, p-type ZnTe has a valence band offset **125** with metal that is significantly smaller than the large valence band offset **105**. Unfortunately, the valence band offset **115** of p-type ZnTe with respect to p-type GaN-based semiconductor is still significant. On the other hand, certain other Group II-VI semiconductors have a smaller valence band offset with the p-type GaN-based semiconductor than valence band offset **115**. For example, p-type ZnSe has a valence band offset **110** with p-type GaN-based semiconductor that is smaller than the valence band offset **115** of p-type ZnSe.

The valence band offset relationships between metal, p-type ZnSe, p-type ZnTe, and p-type GaN-based semiconductor has been used to create an ohmic contact in accordance with the invention. Various exemplary embodiments of such ohmic contacts are described below.

FIG. **2** shows a first exemplary embodiment of an ohmic contact **200** in accordance with the invention. Ohmic contact **200** provides optimal conductivity between a metal contact, in the form of metal layer **205**, and a p-type GaN-based layer **225**. Several layers of semiconductor material are sandwiched between p-type GaN-based layer **225** and metal layer **205**. The semiconductor materials used in these layers generally belong to the Group II-VI family of compound semiconductors. The compound semiconductor of a first layer is characterized by a general formula XY where X is an element selected from Group II and Y is an element selected from Group VI. The compound semiconductor of a second layer is characterized by a general formula XZ where X is an element selected from Group II and Z is an element selected from Group VI that is different than element Y.

In this exemplary embodiment the first compound semiconductor of the first layer includes Zn of Group II and Se of Group VI, while the compound semiconductor of the second layer includes Zn of Group II together with Se, which is a different element selected from Group VI.

Layer **220** of p-type ZnSe is formed on a major surface of GaN-based layer **225**. Layer **220** has a small valence band offset with respect to GaN-based layer **225** thereby providing good electrical conductivity between GaN-based layer **225** and layer **220**.

Layer **210** of p-type ZnTe is formed on a bottom major surface of metal layer **205**. Layer **210** has a small valence band offset with respect to metal thereby providing good electrical conductivity between metal layer **205** and layer **210**.

Sandwiched between layer **220** and layer **210** is a graded bandgap region **215** that can be generally described using a formula $XY_nZ_{1-n}(0<n<1)$ where X is an element from Group II, and Y and Z are two different elements selected from Group VI. In this exemplary embodiment, p-type $ZnSe_xTe_{1-x}$ $(0<x<1)$ is used. Graded bandgap region **215** provides a graded transition for bridging the valence gap offset between layer **220** and layer **210**. At a location close to layer **220** the p-type $ZnSe_xTe_{1-x}(0<x<1)$ has a value of x that is nearly equal to 1, while at a location close to layer **210** the p-type $ZnSe_xTe_{1-x}(0<x<1)$ has a value of x that is nearly equal to 0.

In one embodiment, x varies linearly from 1 to 0 between the two major surfaces of graded bandgap region **215**, with x=0.5 in a mid-region between the two major surfaces. On the other hand, in a second embodiment, x varies non-linearly from 1 to 0 between the two major surfaces of graded bandgap region **215**. For example, x=0.3 in a mid-region between the two major surfaces.

FIG. **3** shows a second exemplary embodiment of an ohmic contact **300** in accordance with the invention. Ohmic contact **300** provides optimal conductivity between a metal contact, in the form of metal layer **305**, and a p-type GaN-based layer **350**. Several layers of semiconductor material are sandwiched between p-type GaN-based layer **350** and metal layer **305**. The semiconductor materials used in these layers generally belong to the Group II-VI family of compound semiconductors. The compound semiconductor of a first layer is characterized by a general formula XY where X is an element selected from Group II and Y is an element selected from Group VI. The compound semiconductor of a second layer is characterized by a general formula XZ where X is an element selected from Group II and Z is an element selected from Group VI that is different than element Y.

Similar to the embodiment shown in FIG. **2**, a layer **345** of p-type ZnSe is formed on a major surface of GaN-based layer **350**, and a layer **310** of p-type ZnTe is formed on a bottom major surface of metal layer **305**. Whereas the embodiment of FIG. **2** shows a continuously graded bandgap region **215**, the exemplary embodiment shown in FIG. **3** incorporates a p-type semiconductor stack **360** having a number of discrete layers. A first set of discrete layers of p-type semiconductor stack **360** are formed of p-type ZnTe, while a second set of discrete layers of p-type semiconductor stack **360** are formed of p-type ZnSe. The first set of discrete layers, which includes ZnTe layers **340**, **330**, and **320**, is interspersed with the second set of discrete layers, which includes ZnSe layers **335**, **325**, and **315**. For example, ZnTe layer **320** is located between ZnSe layers **325** and **315**, while ZnSe layer **335** is located between ZnTe layers **340** and **330**.

On the other hand, the thickness of each individual layer in the first set of discrete layers increases as the individual layer is located further away from GaN-based layer **350**. For example, the thickness of ZnTe layer **340** is smaller than that of ZnTe layer **330**, which in turn has a smaller thickness than ZnTe layer **320**.

The thickness of each individual layer in the second set of discrete layers decreases as the individual layer is located further away from GaN-based layer **350**. For example, the thickness of ZnSe layer **335** is larger than that of ZnSe layer **325**, which in turn is thicker than ZnSe layer **315**.

The variation in thickness described above, has a linear relationship in one exemplary embodiment, and has a non-linear relationship in another exemplary embodiment. In yet another embodiment, the thickness of each individual layer in the first set of discrete layers decreases as the individual layer is located further away from GaN-based layer **350**, while thickness of each individual layer in the second set of discrete layers increases as the individual layer is located further away from GaN-based layer **350**.

In other embodiments, other compound semiconductors are used instead of ZnSe and ZnTe. Some exemplary embodiments are described below using other figures.

FIG. **4** shows a third exemplary embodiment of an ohmic contact **400** in accordance with the invention. Ohmic contact **400** provides optimal conductivity between a metal contact, in the form of metal layer **405**, and a p-type GaN-based layer **425**. Several layers of semiconductor material are sandwiched between p-type GaN-based layer **425** and metal layer **405**. The semiconductor materials used in the various layers belong to the Group II-VI family of compound semiconductors, and are generally characterized by the formula XY where X is an element selected from Group II and Y is an element selected from Group VI.

In this exemplary embodiment, the first compound semiconductor is ZnO and the second compound semiconductor is ZnTe. Layer **420** of p-type ZnO is formed on a major surface of GaN-based layer **425**. Layer **420** has a small valence band offset with respect to GaN-based layer **425** thereby providing good electrical conductivity between GaN-based layer **425** and layer **420**.

Layer **410** of p-type ZnTe is formed on a bottom major surface of metal layer **405**. Layer **410** has a small valence band offset with respect to metal thereby providing good electrical conductivity between metal layer **405** and layer **410**.

Sandwiched between layer **420** and layer **410** is a graded bandgap region **415** that is generally described using a formula $XY_nZ_{1-n}(0<n<1)$ where X is an element from Group II, and Y and Z are two different elements from Group VI. In this exemplary embodiment, p-type $ZnO_xTe_{1-x}(0<x<1)$ is used. Graded bandgap region **415** provides a graded transition for bridging the valence gap offset between layer **420** and layer **410**. At a location close to layer **420** the p-type ZnO_xTe_{1-x} $(0<x<1)$ has a value of x that is nearly equal to 1, while at a location close to layer **410** the p-type $ZnO_xTe_{1-x}(0<x<1)$ has a value of x that is nearly equal to 0.

In one embodiment, x varies linearly from 1 to 0 between the two major surfaces of graded bandgap region **415**, while in a second embodiment, x varies non-linearly from 1 to 0 between the two major surfaces.

FIG. **5** shows a fourth exemplary embodiment of an ohmic contact **500** in accordance with the invention. Several layers of semiconductor material are sandwiched between p-type GaN-based layer **550** and metal layer **505**. Each of these layers contains material that is characterized by the general formula XY where X is an element selected from Group II and Y is an element selected from Group VI. In this fourth exemplary embodiment, the first compound semiconductor is p-type ZnO and the second compound semiconductor is p-type ZnTe.

Layer **545** of p-type ZnO is formed on a major surface of GaN-based layer **550**. Layer **510** of p-type ZnTe is formed on a bottom major surface of metal layer **505**. Sandwiched between layers **545** and **510** is p-type semiconductor stack **560** having a number of discrete layers. A first set of these discrete layers is formed of p-type ZnTe layers, while a second set of discrete layers of p-type semiconductor stack **560** are formed of p-type ZnO layers. The first set of discrete layers, which includes ZnTe layers **540**, **530**, and **520**, is interspersed with the second set of discrete layers, which includes ZnO layers **535**, **525**, and **515**. For example, ZnTe layer **520** is located between ZnO layers **525** and **515**, while ZnO layer **535** is located between ZnTe layers **540** and **530**.

The thickness of each individual layer in the first set of discrete layers increases as the individual layer is located further away from GaN-based layer **550**. For example, the thickness of ZnTe layer **540** is smaller than that of ZnTe layer **530**, which in turn has a smaller thickness than ZnTe layer **520**.

The thickness of each individual layer in the second set of discrete layers decreases as the individual layer is located further away from GaN-based layer **550**. For example, the thickness of ZnO layer **535** is larger than that of ZnO layer **525**, which in turn is thicker than ZnO layer **515**.

The variation in thickness described above, has a linear relationship in one exemplary embodiment, and has a non-linear relationship in another exemplary embodiment. In yet another embodiment, the thickness of each individual layer in the first set of discrete layers decreases as the individual layer is located further away from GaN-based layer **550**, while thickness of each individual layer in the second set of discrete layers increases as the individual layer is located further away from GaN-based layer **550**.

FIG. **6** shows a fifth exemplary embodiment of an ohmic contact **600** in accordance with the invention. Ohmic contact **600** provides optimal conductivity between a metal contact, in the form of metal layer **605**, and a p-type GaN-based layer **625**. In this exemplary embodiment, the metal of metal layer **605** is a metal other than Indium, for example, gold.

Sandwiched between metal layer **605** and p-type GaN-based layer **625** is a continuously graded bandgap region **615** that is generally described using a formula $Ga_xIn_{1-x}N_y$ $(0 \leqq x<1)$ and $(0 \leqq y \leqq 1)$. Graded bandgap region **615** provides a graded transition for bridging the valence gap offset between metal layer **605** and p-type GaN-based layer **625**. At a first location close to the p-type GaN-based layer **625**, bandgap p-type region **615** contains $Ga_xIn_{1-x}N_y$ with $(0<x<1)$ and $(0<y<1)$. At a second location in an intermediate portion between p-type GaN-based layer **625** and metal layer **605**, bandgap p-type region **615** contains only InN, Ga being eliminated with $(x=0)$ and $(y=1)$. At a third location, close to metal layer **605**, the bandgap p-type region **615** contains only one element—Indium, N being eliminated with $(x=0)$ and $(y=0)$. Because Indium is a metal, this portion of bandgap p-type region **615** provides optimal valence band matching with metal layer **605**.

In one embodiment, x and y vary linearly between the first major surface of graded bandgap region **615** located adjacent to p-type GaN-based layer **625**, and the other major surface located adjacent to metal layer **605**.

In another embodiment, x and y vary non-linearly between the first major surface of graded bandgap region **615** located adjacent to p-type GaN-based layer **625**, and the other major surface located adjacent to metal layer **605**.

FIG. **7** shows a sixth exemplary embodiment of an ohmic contact **700** in accordance with the invention. Indium is used as the metal of the metal contact of ohmic contact **700**. Consequently, in this alternative embodiment, bandgap p-type region **715**, which is located adjacent to p-type GaN-based layer **725** extends all the way to the top surface of ohmic contact **700**.

The above-described embodiments are merely set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made without departing substantially from the disclosure. All such modifications and variations are included herein within the scope of this disclosure.

We claim:

1. An ohmic contact comprising:

a layer of p-type GaN-based material;

a first layer of p-type group II-VI compound semiconductor material comprising a first group VI element, the first layer located adjacent to the layer of p-type GaN-based material;

a layer of metal configured to provide a metal contact;

a second layer of p-type group II-VI compound semiconductor material comprising a second group VI element different than the first group VI element, the second layer located adjacent to the layer of metal; and

a p-type semiconductor stack sandwiched between the first layer and the second layer, the p-type semiconductor stack comprising:

a third layer of p-type group II-VI compound semiconductor material comprising the first group VI element and excluding the second group VI element; and

a fourth layer of p-type group II-VI compound semiconductor material located adjacent the third layer, the fourth layer comprising the second group VI element and excluding the first group VI element.

2. The ohmic contact of claim **1**, wherein the p-type GaN-based material is $In_xAl_yGa_{1-x-y}N$.

3. The ohmic contact of claim **2**, wherein:

the first layer of p-type group II-VI compound semiconductor material has a general formula XY wherein X is an element selected from group II and Y is the first group VI element;

the second layer of p-type group II-VI compound semiconductor material has a general formula XZ wherein X is an element selected from group II and Z is the second group VI element;

the third layer of p-type group II-VI compound semiconductor material is located adjacent to the first layer and has the general formula XZ wherein X is the element selected from group II and Z is the second group VI element; and

the fourth layer of p-type group II-VI compound semiconductor material is located adjacent to the third layer and has the general formula XY wherein X is the element selected from group II and Y is the first group VI element.

4. The ohmic contact of claim **3**, wherein a first valence band offset between the second layer of the p-type group II-VI compound semiconductor material and the layer of metal is less than a second valence band offset between the layer of p-type GaN-based material and the layer of metal.

5. The ohmic contact of claim **4**, wherein the first layer comprises a first one of a) ZnTe, b) ZnSe, and c) ZnO and wherein the second layer comprises a second one of a) ZnTe, b) ZnSe, and c) ZnO, the first one being different than the second one.

6. The ohmic contact of claim **5**, wherein the p-type semiconductor stack has a plurality of layers comprising:

a first set of layers each containing the p-type group II-VI compound semiconductor comprising the first group VI element;

a second set of layers each containing the p-type group II-VI compound semiconductor comprising the second group VI element; and wherein each of the first set of layers is interspersed with each of the second set of layers.

7. The ohmic contact of claim **6**, wherein:

layer thickness of each individual layer of the first set of layers increases as the individual layer is located further away from the p-type GaN-based material; and

layer thickness of each individual layer of the second set of layers decreases as the individual layer is located further away from the p-type GaN-based material.

8. The ohmic contact of claim **7**, wherein the layer of metal comprises at least one of gold and platinum.

* * * * *